High-accuracy curved lattice Boltzmann boundary conditions for efficient GPU simulations

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With the lattice Boltzmann Method (LBM), a straightforward extension of the bounce-back no-slip rule leads to a vast group of directional (aka link-wise) Dirichlet boundary conditions. These methods can accurately describe the interaction of a fluid flow with a complex solid surface in a uniform Cartesian grid. The link-wise family includes an infinite number of schemes that can be tuned to optimize their five fundamental features: (i) exactness of channel flows velocity and pressure profiles, (ii) accuracy order, (iii) linear stability, (iv) parametrization, and (v) locality. We identify, respectively, two main groups of directional schemes. The first comprises compact schemes with linear exactness (LI) (Ginzburg et al., 2008) and its extended local (ELI) family (Ginzburg et al., 2022; Marson, 2022; Marson et al., 2021), which combines the local single-node implementation with the second-order accuracy, linear exactness, and physical consistency. The second is the Multi-reflection (MR) family, which gains parabolic exactness in the Stokes and Navier-Stokes flows but loses locality. This presentation focuses on the new developments of ELI, which provide ELI (and LI) with parabolic exactness in Stokes flows. Additionally, it shows how these schemes allow for simple and uniform implementations, even in the coarsest simulations characterized by many narrow gaps. One can implement ELI simply by modifying the collision model in the boundary node where the half-way bounce-back (HW) applies. Therefore, the implementation in a high-performance code is straightforward. We implement ELI in GPU-accelerated Palabos (Latt et al., 2021a, 2021b), which allows for multi-GPU simulations, showing that one can obtain outstanding numerical performances which are close to the ones of the HW for steady boundaries.

References

[1] Ginzburg, I., Silva, G., Marson, F., Chopard, B., Latt, J., 2022. Unified directional parabolic-accurate Lattice Boltzmann boundary schemes for grid-rotated narrow gaps and curved walls in creeping and inertial fluid flows. Phys. Rev. E Submitted. 51.

[2] Ginzburg, I., Verhaeghe, F., d'Humières, D., 2008. Two-Relaxation-Time Lattice Boltzmann Scheme: About Parametrization, Velocity, Pressure and Mixed Boundary Conditions. Commun Comput Phys 3, 427–478.

[3] Latt, J., Malaspinas, O., Kontaxakis, D., Parmigiani, A., Lagrava, D., Brogi, F., Belgacem, M.B., Thorimbert, Y., Leclaire, S., Li, S., Marson, F., Lemus, J., Kotsalos, C., Conradin, R., Coreixas, C., Petkantchin, R., Raynaud, F., Beny, J., Chopard, B., 2021a. Palabos: Parallel Lattice Boltzmann Solver. Comput. Math. Appl., Development and Application of Open-source Software for Problems with Numerical PDEs 81, 334–350. https://doi.org/10.1016/j.camwa.2020.03.022

[4] Latt, J., Marson, F., De Santana Neto, J.P., Thyagarajan, K., Coreixas, C., Chopard, B., 2021b. From CPU to GPU in 80 days. https://doi.org/10.13140/RG.2.2.10340.71046

[5] Marson, F., 2022. Directional lattice Boltzmann boundary conditions

[6] Marson, F., Thorimbert, Y., Chopard, B., Ginzburg, I., Latt, J., 2021. Enhanced single-node lattice Boltzmann boundary condition for fluid flows. Phys. Rev. E 103, 053308. https://doi.org/10.1103/PhysRevE.103.053308